RED-SHOULDERED HAWK NEST SITE SELECTION IN NORTH-CENTRAL MINNESOTA

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ABSTRACT.—We evaluated characteristics at Red-shouldered Hawk (*Buteo lineatus*) nest sites at two study areas with different topography and forest types in north-central and central Minnesota to identify nest site commonalities across geographically distinct areas. During the breeding seasons of 1994–1995, we located nests of Red-shouldered Hawks at the Camp Ripley Army National Guard Training Site and the Chippewa National Forest using a combination of broadcast surveys, helicopter searches, and systematic foot searches. All 38 nests at Camp Ripley and 18 nests in the Chippewa National Forest were in upland hardwood stands; the remaining two nests in the Chippewa National Forest were in aspen (*Populus* spp.) stands. We aged cores from 19 nest trees at Camp Ripley and measured habitat characteristics in a 0.04 ha circle centered on each nest tree and at a paired random site within the nest stand. We compared habitat variables at nest and random sites to identify habitat characteristics that were consistent predictors of nest sites versus random sites for each study area and for all nests combined. Compared to random sites, nest sites in the Chippewa National Forest had larger diameters at breast height (dbh) of the nest tree, taller nest tree height, and higher canopy height. At Camp Ripley, nest sites differed from random sites with regard to many more variables; nests were located in portions of the stand with larger trees and closer to surface water. Nest trees ranged in age from 50–89 years. Logistic regression models indicated that, for both study areas combined, nest tree dbh, basal area, canopy height, and distance to water were the most important variables in distinguishing nest sites from random sites. *Received 31 August 1999, accepted 12 Feb. 2000.*

Red-shouldered Hawk (*Buteo lineatus*) population declines (Brown 1971, Bednarz et al. 1990), projected increases in rates of timber harvest (Jaakko Pöyry Consulting 1992), and observations that canopy thinning may result in displacement of Red-shouldered Hawks by Red-tailed Hawks (*Buteo jamaicensis*; Bryant 1986) have led to increased concern about the availability of nesting habitat for Red-shouldered Hawks in Minnesota and elsewhere. Descriptions of Red-shouldered Hawk nesting habitat have been reported from bottomland forests in eastern, central, and south-central parts of the U.S. (Henny et al. 1973; Bednarz and Dinsmore 1981, 1982; Preston et

al. 1989) and from upland mixed forests in the eastern U.S. and southern Canada (Portnoy and Dodge 1979, Armstrong and Euler 1982, Morris et al. 1982, Bosakowski et al. 1992). Red-shouldered Hawk nest sites have been distinguished from generally available forested habitat (as defined by a canopy height ≥ 10 m) within several km of the nest (Titus and Mosher 1981, Morris and Lemon 1983, Mosher et al. 1986, Preston et al. 1989) or from nest sites of other raptor species (Armstrong and Euler 1982) by the presence of mature hardwood stands, although details of vegetation characteristics varied from site to site.

Red-shouldered Hawk populations in Minnesota have been predicted to decline in the future (Jaakko Pöyry Consulting 1992) based on studies of habitat use from other portions of the species' breeding range and the projected increase in harvest rates of northern hardwood forests. The only previous description of nest site habitat characteristics for Red-shouldered Hawks in Minnesota came from four nests in the southeast corner of Minnesota along tributaries of the Mississippi River and from four nests in north-central Minnesota (Mosher 1987). Within-stand habitat characteristic comparisons in Minnesota may suggest which attributes of nest sites influence

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habitat selection and are associated with successful nesting, and allow managers to better incorporate Red-shouldered Hawk management into forest harvest strategies. We describe Red-shouldered Hawk nest sites in central and north-central Minnesota at the northern edge of the species' breeding range, compare nest sites to random sites within the nest stand, compare habitat characteristics at successful versus unsuccessful nests, and describe logistic regression models that identify habitat characteristics that appear to be associated with nest site selection within the stand.

STUDY AREA AND METHODS

Study area.—We conducted the study at two sites in central and north-central Minnesota: the Camp Ripley Army National Guard Training Site and neighboring state and private land (hereafter Camp Ripley); and the Chippewa National Forest (hereafter the Chippewa). The Camp Ripley Army National Guard Training Site (46° 15′ N, 94° 25′ W) covers approximately 20,000 ha in Morrison County and is bounded by the Crow Wing River on the north and the Mississippi River on the east. Neighboring areas included The Nature Conservancy Lake Alexander Preserve (approximately 1400 ha; 46° 11′ N, 94° 30′ W) and the Pillsbury State Forest (approximately 1300 ha; 46° 22′ N, 94° 26′ W). The northern half of the Camp Ripley Army National Guard Training Site is a glacial moraine characterized by irregular rolling hill topography with interspersed wetlands and vegetated primarily by upland hardwood forest. This area contains two contiguous, approximately 375 ha blocks of mature (50–75 years old) hardwood forest. The Nature Conservancy Lake Alexander Preserve consists of largely contiguous upland hardwood forests with a network of old logging trails and scattered overstory red (*Pinus resinosa*) and white pine (*P. strobus*). Pillsbury State Forest consists of a mosaic of even-aged (50–70 years old) upland hardwood stands with scattered overstory pine, regenerating aspen (*Populus* spp.) stands of varying ages and sizes, pine plantations, and secondary roads and trails.

The Chippewa covers approximately 600,000 ha of Cass and Itasca counties in north-central Minnesota, in the transition zone from hardwood to boreal forest. Northern hardwood stands are scattered through the forest, generally in patches smaller than 30 ha and are interspersed with ash (*Fraxinus* spp.) swamps, marshes, and other wet areas. The most extensive area of hardwoods on the Chippewa, on the north side of Leech Lake (47° 15′ N, 94° 25′ W), covers approximately 6400 ha and contains several stands of at least 100 ha. This area lies on the Guthrie till plain; soils are wet and topography is generally flat. These stands were last logged early in the 20th century. For a more detailed description of the study areas, see McLeod and Andersen (1998).

Locating nests.—We located Red-shouldered Hawk nests using a variety of methods. In 1991 and 1992 at Camp Ripley and in 1994 and 1995 on Camp Ripley and the Chippewa, we used audio broadcasts to survey for Red-shouldered Hawks in a variety of forest types. Preliminary surveys in 1991 and 1992 at Camp Ripley consisted of broadcasting Red-shouldered Hawk alarm calls from roads 3 times for 20 seconds at 3 minute intervals. We broadcast calls at 90 different locations (separated by ≥0.6 km along roads) throughout all forested portions of Camp Ripley, where forest stands were at least 30 years of age. In 1994 and 1995, surveys consisted of broadcasting six sets of Red-shouldered Hawk alarm calls or Great-horned Owl (*Bubo virginianus*) hoots at 1 minute intervals and listening and looking for Red-shouldered Hawk responses (see McLeod and Andersen 1998 for survey protocol details). We detected Red-shouldered Hawks in areas of mature hardwood forest; consequently, we focused searches for nests on this forest type. In 1995, we systematically searched two approximately 375 ha forest blocks at Camp Ripley for nests before the leaves came out with one to four observers scanning for nest structures and walking parallel transects approximately 50 m apart. We also used helicopter searches in portions of Camp Ripley following the methodology of Cook and Anderson (1990). We conducted foot searches at both study areas in 1994 and 1995 as follow-ups to responses from broadcast surveys (McLeod and Andersen 1998) or checks of historic nest sites. In 1995, we searched areas where Red-shouldered Hawks had been detected after tree leaf development in 1994 hindered searching for nests. Local residents or personnel from field crews conducting unrelated research reported six nests in the Chippewa. We determined stick structures to be Red-shouldered Hawk nests either by the presence of an adult Red-shouldered Hawk in or near the nest or by the presence of fresh greenery or down feathers on the nest and vocalizing adult Red-shouldered Hawks in the vicinity. We located one nest in the Chippewa late in the season and determined it to be a Red-shouldered Hawk nest by the presence of molted Red-shouldered Hawk feathers on the ground under the nest. We used binoculars to monitor nests from the ground every 5–10 days. Because young were difficult to detect after they left the nest, we defined a nest as successful if at least one chick survived to 28 days of age [approximately 65% of the average nestling period of 43 days (Crocoll 1994)]. We based nestling age estimates on feather growth (J. Stravers, unpubl. data). Because we could not always determine whether eggs had been laid, we defined unsuccessful nests as those that did not produce young at least 28 days of age, regardless of whether we observed incubation.

For our results to be useful in describing characteristics that distinguish nest sites from available habitat, we needed to locate nests in a manner that did not result in sampling biases (see Daw et al. 1998). We focused our search efforts on mature northern hardwood forest because the literature and preliminary

broadcast surveys at both study areas suggested Red-shouldered Hawks would be found in that forest type. However, in 1994 we ran repeated broadcast surveys in the Chippewa in a variety of forest types (including aspen-birch, pine, cedar, and fragmented bottomland hardwoods) and did not hear any vocalizations from Red-shouldered Hawks in forest types other than northern hardwoods (M. A. McLeod, unpubl. data). Although we found some nests as the result of responses to broadcast surveys from roads, birds responded from nests as far as 800 m from survey stations (M. A. McLeod, unpubl. data). We also thoroughly searched approximately 775 ha at Camp Ripley on foot for nest structures without regard to the presence of roads, and additional areas were searched from the air. The responsiveness of Red-shouldered Hawks to broadcast surveys (McLeod and Andersen 1998), coupled with the ubiquitous nature of roads in our study areas, suggests our sample was not biased toward nests located near roads and we are aware of no other potential location bias.

Measurement of site characteristics.—After young fledged or the nest failed, we measured habitat characteristics (Table 1) at all nest sites following a modification of methods outlined by James and Shugart (1970). We defined the nest site as the 11.3 m radius (0.04 ha) circle centered on the nest tree. For each nest site, we located a random point within the nest stand in a random compass direction and at a random distance 75–200 m from the nest tree. We defined the nest stand as an area with the same forest type and comparable stocking density as the nest site and not separated from the nest by roads or harvested areas. We centered each random site on the tree at least 23 cm diameter at breast height (dbh; diameter of the smallest Red-shouldered Hawk nest tree found in 1994) nearest to the random point. Except for variables specific to the nest, we made the same measurements at random sites as at the nest sites.

We cored 25 nest trees at Camp Ripley using an increment borer. Six cores were incomplete because of heart rot and were excluded from analyses. We aged aspen cores using a modification of Campbell (1981; W. H. Lane, pers. comm.) from the cork cambium toward the center, adding five years to adjust for the 1.37 m drilling height (K. Puettmann, pers. comm.).

Data analyses.—We used two-tailed paired *t*-tests to determine which of the 26 habitat variables (except for slope direction) common to nest and random sites potentially differed ($P < 0.05$) between nest sites and random sites in the Chippewa, at Camp Ripley, and for both areas combined. Subsequent to univariate tests, we constructed logistic regression models (see below) to evaluate the simultaneous influence of habitat variables; thus, we did not attempt to control experiment-wise error by adjusting for multiple comparisons in univariate tests. We used Raleigh tests (Zar 1998) for random angular distribution to evaluate downhill slope direction of nest sites in the Chippewa and at Camp Ripley. We used Bonferroni Z-statistics (as reviewed by Alldredge and Ratti 1992 and using

the modification suggested by Agresti and Coull 1998) to determine which tree species were used out of proportion to their availability (simultaneous $\alpha = 0.05$). We used two-tailed *t*-tests to compare habitat characteristics at successful versus unsuccessful nests at Camp Ripley. We excluded the two nest sites where breeding occurred in both years and young were fledged in one year but not the other from the analysis of factors potentially related to nesting success. We also excluded the five nests where egg laying was confirmed (incubation or chicks observed) and failure occurred more than one week after the median hatch date because nest failures that occur more than one week after hatching are likely to be the result of factors other than those that cause failures earlier in the nesting season (Newton 1979). We calculated failure dates for unsuccessful nests as the day halfway between the last observed activity and the date when no further activity was observed, and we determined hatching dates for individual nests by back-dating from the estimated age of the oldest chick in the nest as determined upon banding ($n = 12$) or from observation of chicks ($n = 16$). Nests in the Chippewa were not included in the analysis of successful versus unsuccessful nests because of the low number of successful nests ($n = 2$).

In addition to univariate comparisons, we used nominal logistic regression (Fienberg 1980) to model the predictive power of habitat variables in determining whether sites were nest or random locations. We used cluster analysis to reduce the number of predictor variables used in the logistic models. For each variable, we calculated the difference between the value at a nest site and the average of the values at the nest and paired random site. We clustered these differences for the combined study areas using average linkage (SAS Institute, Inc. 1994). For each cluster joined within a distance of 1.3, we chose one variable based on its usefulness in describing stand structure or common use by foresters to be included in the modeling. We included a variable that identified the nest site and its paired random site in all models to block for location effects.

We created logistic regression models by forward selection on the habitat variables remaining after cluster analysis. We ordered these variables randomly and entered the first two variables into the model. We eliminated the variable with the lower likelihood ratio χ^2 if its P value was greater than 0.05. We added variables one at a time, in predetermined random order, and after each addition eliminated the variable with the lowest χ^2 value if its P value was greater than 0.05. We terminated variable selection if the addition of a variable resulted in a perfect fit and failure of the model to converge or when all predictor variables had been evaluated in the model selection procedure. For each grouping of nests (Chippewa, Camp Ripley, all) we created ten different random orders of variables and conducted forward selection for each random order. We also created a model to test for interactions between site and habitat variables that appeared consistently ($\geq50\%$ of models) in the models of all nests.

TABLE 1. Sample means (x̄) and standard deviations (SD) for variables measured or derived at all Red-shouldered Hawk nest sites and paired random sites, Chippewa National Forest, Camp Ripley, and both sites combined, 1994 and 1995. Sample size indicates number of nests at each site. An asterisk (*) indicates that nest sites differed from their paired random points (paired t-tests, $P < 0.05$).

Variable	Chippewa (n = 20)				Ripley (n = 38)				Both (n = 58)			
	Nest		Random		Nest		Random		Nest		Random	
	x̄	SD	x̄	SD	x̄	SD	x̄	SD	x̄	SD	x̄	SD
Distance from the ground to the bottom of the nest[a,b] (m)	13.2	1.9	—	—	14.6	2.2	—	—	14.1	2.2	—	—
DBH of the plot-center tree (cm)	47.1*	9.2	37.0	9.0	41.7*	7.7	35.5	8.4	43.6*	8.6	36.0	8.6
Height of the plot-center tree[a] (m)	24.2*	2.6	22.1	3.3	25.0*	2.7	22.7	3.2	24.8*	2.7	22.5	3.3
Nest height/plot-center tree height × 100 (%)	54.7	5.7	—	—	58.4	8.1	—	—	57.2	7.5	—	—
Elevation of the plot[c] (m)	421.2	11.5	420.0	10.2	403.8*	21.7	408.3	21.0	409.8*	20.5	412.4	18.7
Slope across the plot[d] (deg)	2.4	1.9	3.0	2.6	6.3	4.3	6.9	4.9	4.9	4.1	5.6	4.6
Canopy closure at the nest tree[e] (%)	93.4	3.8	93.9	3.5	92.1	4.9	92.0	4.5	92.6	4.7	92.7	4.2
Canopy closure in the four quadrants[f] (%)	93.8	2.9	93.6	2.6	92.7	3.1	92.2	3.3	93.1	3.1	92.7	3.1
Canopy closure of the plot[g] (%)	93.7	3.0	93.7	2.7	92.6	3.2	92.2	3.2	93.0	3.2	92.7	3.1
Canopy height (m); average of 4 readings, one in each quadrant[a]	18.6*	2.3	17.2	1.9	19.4*	2.4	17.7	3.0	19.1*	2.3	17.5	2.7
Understory cover[h] (%)	66.9	12.5	71.6	10.5	80.1	13.6	81.3	14.5	75.6	14.7	78.9	13.8
Ground cover[h] (%)	49.1	11.0	44.2	17.1	56.6	23.9	57.1	25.2	54.3	20.7	52.5	23.2

TABLE 1. CONTINUED.

Variable	Chippewa (n = 20)				Ripley (n = 38)				Both (n = 58)			
	Nest		Random		Nest		Random		Nest		Random	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Number of shrubs within 5 m of plot center[l]	100.6	82.5	101.8	78.1	66.0	57.1	77.5	77.7	77.9	68.3	86.3	78.6
Height of dominant shrub species (m)	2.1	0.9	2.2	1.2	1.5*	0.7	1.9	1.3	1.7	0.8	2.0	1.2
Basal area for all trees in the plot[j] (m²/ha)	34.2	6.9	32.4	8.4	27.6*	7.8	23.2	6.3	29.9*	8.1	26.4	8.3
Average dbh for all trees in the plot (cm)	22.8	2.8	22.4	3.3	22.0*	3.7	20.1	2.8	22.3*	3.4	20.9	3.1
Average dbh for all overstory trees on the plot[k] (cm)	31.4	4.0	30.3	5.9	32.8*	6.1	28.9	4.9	32.3*	5.4	29.4	5.3
Number of overstory trees[k]	14.9	4.5	15.9	7.8	10.8	5.0	11.1	4.4	12.2	5.2	12.8	6.1
Number of understory trees[l]	11.5	4.5	10.8	3.8	12.6	5.4	12.6	5.3	12.2	5.1	12.0	4.9
Number of dead stems ≥ 8 cm dbh and ≥ 2 m in height	3.3	2.0	3.6	3.6	3.1	2.5	3.9	2.4	3.1	2.3	3.8	2.9
Total number of trees[j]	29.7	7.8	30.2	7.6	26.5	8.8	27.6	7.1	27.6	8.5	28.9	13.1
Distance to surface water[m] (m)	88.8	73.7	86.9	75.5	108.2*	99.6	136.6	119.9	101.5*	91.3	119.5	108.6
Distance to a road (m; 4WD track, gravel, or paved)[m]	328.9	254.8	323.9	252.6	282.3	169.1	284.0	192.4	298.3	201.8	297.8	213.7

TABLE 1.   CONTINUED.

Variable	Chippewa (n = 20)				Ripley (n = 38)				Both (n = 58)			
	Nest		Random		Nest		Random		Nest		Random	
	x̄	SD	x̄	SD	x̄	SD	x̄	SD	x̄	SD	x̄	SD
Distance to nearest harvest activity[m] (m)	286.5	186.4	276.2	155.5	327.0	219.7	338.0	193.8	313.0	208.1	316.7	182.5
Trees in the plot 8–12.4 cm dbh (%)	24.3	11.1	26.4	10.1	27.5	12.9	31.5	14.2	26.4	12.3	29.7	13.1
Trees in the plot 12.5–22.6 cm dbh (%)	31.6	9.9	32.5	13.7	33.0	13.4	32.0	14.0	32.5	12.2	32.1	13.8
Trees in the plot 22.7–37.8 cm dbh (%)	29.4	9.1	27.7	10.9	26.8	14.2	29.5	14.2	27.6	12.7	28.9	13.1
Trees in the plot ≥37.9 cm dbh (%)	14.7	9.1	13.4	9.6	12.8*	10.9	7.0	6.9	13.4*	10.0	9.2	8.4

[a] Height was measured using a clinometer. Distances used to calculate height were measured with a tape.

[b] Variable is specific to the nest tree and therefore not applicable to random sites.

[c] Determined from 7.5 min U.S. Geological Survey (USGS) quadrangle maps.

[d] Measured with a clinometer.

[e] Measured using a convex densiometer. Four readings were taken, one in each cardinal direction, facing away from the nest tree. If necessary, the observer stepped away from the nest tree so the bole was not counted as a significant portion of the canopy.

[f] Measured with a convex densiometer at 8.5 m from plot center in each of the four cardinal directions. Four readings were taken at each point, one in each cardinal direction. All 16 measurements were averaged.

[g] Average of the 16 quadrant canopy closure and four nest tree canopy closure measurements.

[h] Measured at 1-m intervals between 1 and 10 m, inclusive, from plot center in each cardinal direction, using an ocular tube as described in James and Shugart (1970).

[i] A shrub was any live woody stem <8 cm dbh and >50 cm in height. Stem numbers were counted at a height of 10 cm.

[j] A tree was any live stem >8 cm dbh.

[k] An overstory tree was any live stem >8 cm dbh whose major foliage fell in the upper third of the overall stand height.

[l] An understory tree was any live stem >8 cm dbh whose major foliage fell in the bottom two thirds of the stand height.

[m] Distance was paced if <100 m; otherwise it was estimated from 1:15,400 aerial photographs or 7.5 min USGS quadrangle maps.

We eliminated cross terms with $P > 0.05$ one at a time, starting with the highest P value, until all remaining terms had $P < 0.05$. We used logistic regression rather than discriminant function analysis because logistic regression does not depend on normality of the data (Fienberg 1980). All statistical analyses used JMP® software (version 3.1.5 for Macintosh, SAS Institute, Inc. 1994).

RESULTS

We located 5 Red-shouldered Hawk nests in the Chippewa in 1994 and 15 additional nests in 1995. None of the 1994 nests was reused in 1995, nor did we find active nests in 1995 in the vicinity of any of the 1994 nests. Of the 20 nests, 17 were unsuccessful and 2 produced a single chick each. Success of the remaining Red-shouldered Hawk nest was undetermined because we located it late in the season, after all nestlings in our sample of nests had fledged. Abundant whitewash beneath the nest suggested that at least one chick reached fledging age. Eighteen of the 20 nests were in mature northern hardwood stands; the remaining two were in mature aspen stands. Nests were found in paper birch (*Betula papyrifera*; 5), sugar maple (*Acer rubrum*; 5), yellow birch (*B. alleghaniensis*; 3), quaking aspen (*Populus tremuloides*; 3), red oak (*Quercus rubra*; 2), bur oak (*Q. macrocarpa*; 1), and balsam poplar (*P. balsamifera*; 1). Nest tree use did not differ from availability for any tree species.

We located 19 nests at Camp Ripley in 1994. In 1995, 10 of these nest structures appeared to be used by Red-shouldered Hawks, and we located 19 additional nests, none of which was in breeding areas where we had found nests in 1994. Thirteen of the 19 nests produced young in 1994. In 1995, 15 of the 29 nests produced young. We found nests in quaking aspen (20), red oak (12), big-tooth aspen (*Populus grandidentata*; 3), paper birch (2), and white oak (*Quercus alba*; 1). All nests were in mature upland hardwood stands. Nest trees were not selected in proportion to their availability ($z = 5.49$, $P < 0.001$), with quaking aspen used more than expected. Nests at both study sites tended to be in large diameter trees in closed canopy mature forest and close to water (Table 1). Nest tree age at Camp Ripley averaged 59 years (range: 50–76, $n = 8$) for aspen and 67 years (range: 54–89, $n = 11$) for oak.

Nest sites in the Chippewa had larger nest tree dbh and higher nest tree height and canopy height than their paired random sites ($t = 4.21$, $P < 0.001$; $t = 2.38$, $P = 0.03$; $t = 2.13$, $P = 0.047$; respectively: 19 df for all tests) as did nest sites at Camp Ripley ($t = 3.33$, $P = 0.002$; $t = 2.98$, $P = 0.005$; $t = 2.76$, $P = 0.009$; respectively: 37 df). Relative to their paired random sites, nest sites at Camp Ripley were also at a lower elevation and closer to permanent water ($t = -3.41$, $P = 0.002$; $t = -3.06$, $P = 0.004$; respectively: 37 df), and had shorter shrub height, larger basal area, larger average dbh of all trees, larger average dbh of overstory trees, and a higher percentage of large (≥ 37.9 cm dbh) trees ($t = -2.09$, $P = 0.04$; $t = 2.88$, $P = 0.007$; $t = 2.89$, $P = 0.006$; $t = 3.29$, $P = 0.002$; $t = 2.93$, $P = 0.006$; respectively; 37 df). Downhill slope direction of nest sites at Chippewa was not significantly different from random (Rayleigh's $z = 2.090$, $n = 17$, R = 5.96, $P > 0.05$) but at Camp Ripley nest sites were located more often on north-facing sites (mean direction = 32°, Rayleigh's $z = 4.244$, $n = 38$, R = 12.70, $P = 0.01$). At Camp Ripley, successful nests had more small trees (8–12.4 cm dbh; $t = 2.30$, 29 df, $P = 0.03$) and were closer to harvest activity ($t = 3.14$, 29 df, $P = 0.004$) than random sites.

Cluster analysis reduced the number of potential predictor variables in the logistic regression modeling from 26 to 19. Canopy cover of the plot was selected from a cluster with canopy cover at the nest tree, canopy cover away from the nest tree, ground cover, understory cover, number of snags, and shrub height. Diameter at breast height of overstory trees was chosen from a cluster with average dbh of all trees in the plot. Of the 19 remaining habitat characteristics, nest tree dbh and percent of medium-small (12.5–22.6 cm dbh) trees were statistically significant predictors of nest sites versus random sites in the Chippewa in more than 5 logistic regression models. Distance to permanent water, percent of small (8–12.4 cm dbh) trees, percent of large (≥ 37.9 cm dbh) trees, canopy height, number of understory trees, total number of trees, and distance to a road were significant in 1–4 of the 10 models. Five of the models terminated in perfect fits. At Camp Ripley, distance to permanent water, nest tree dbh, basal area, dis-

tance to a road, and average dbh of overstory trees were statistically significant predictors in at least 5 models, and 10 variables were significant in 1–4 models. When all nest sites were analyzed together, nest tree dbh, distance to permanent water, basal area, and canopy height were significant in 5 or more models. Average dbh of overstory trees, number of overstory trees, distance to harvest activity, elevation, slope, percent of small trees, and percent of medium-small trees were significant in 1–4 models. Basal area and distance to permanent water interacted significantly with study area, but nest tree dbh and canopy height did not. For both basal area and distance to permanent water, parameter estimates indicated the variables were important predictors at Camp Ripley but not in the Chippewa.

DISCUSSION

The significance of nest tree dbh and nest tree height in univariate tests for both study areas and the consistent appearance of nest tree dbh as a significant predictor of nest site in logistic regression models indicate that within mature hardwood stands in central and north-central Minnesota, Red-shouldered Hawks selected relatively large trees in which to place their nests. These results are consistent with other studies (Bednarz and Dinsmore 1982, Woodrey 1986, Titus and Mosher 1987, Johnson 1989). The selection of quaking aspen out of proportion to its availability is probably the result of differences in growth forms. Aspens and birches often form crotches capable of supporting nests, whereas other canopy and overstory trees, such as American basswoods (*Tilia americana*), seldom do. Other authors (Bednarz and Dinsmore 1982, Morris et al. 1982, Titus and Mosher 1987) have suggested that tree structure rather than species is important in nest tree selection.

Nest sites also differed from random sites. Canopy height was higher at nest sites than at random sites at both study areas, indicating that the trees surrounding the nest, as well as the nest tree, were taller than trees at the corresponding random sites. Preston and coworkers (1989) reported that Red-shouldered Hawk nest sites in Arkansas had a taller canopy than sites selected randomly in the same forest type, and Woodrey (1986) found that nest sites

in Ohio had taller canopies than random plots located within 75 m of the nest.

There was a tendency at Camp Ripley for Red-shouldered Hawks to avoid placing their nests on south-facing slopes. Johnson (1989) also reported this trend for Red-shouldered Hawk nests in north-central New York. It is unclear why Red-shouldered Hawks would prefer one aspect to another. In the Chippewa, slope is so slight that aspect is unlikely to have any effect on exposure of the nest. Slopes are steeper at Camp Ripley and their direction might be more likely to affect microclimate at the nest.

Several variables that did not differ between nest and random sites in the Chippewa differed at Camp Ripley. Elevation and distance to permanent water differed between nest and random sites at Camp Ripley, and distance to permanent water was significant in every Camp Ripley logistic regression model, suggesting Red-shouldered Hawks at Camp Ripley place their nests close to water. The upland hardwood areas of Camp Ripley have irregular rolling hills that typically rise 10–35 m above adjacent wetlands and ponds, so a site near water also tends to be lower in elevation than the surrounding area. Other researchers have found Red-shouldered Hawks to be associated with riparian areas and wetlands (Henny et al. 1973, Portnoy and Dodge 1979, Bosakowski et al. 1992). In the Chippewa, 14 of the 20 nests were in the flat Guthrie till plain. Ash swamps, marshes, and bogs are interspersed throughout the area. Both nest and random sites in the Chippewa tended to be closer to water than nest sites at Camp Ripley, suggesting that the ubiquitous nature of water in this part of the Chippewa removes proximity to water as a factor in Red-shouldered Hawk nest site selection. These results do not indicate that habitat characteristics that were factors in nest site selection in one area do not influence nest site selection in another. Rather, the predominance of some habitat features, such as water, in some landscapes makes it difficult to detect the importance of these features because all potential sites are acceptable with regard to that character.

Forest characteristics indicating the presence of large trees were significant in distinguishing nest sites from random sites at Camp Ripley but not in the Chippewa. Basal area,

average dbh of overstory trees, average dbh of all trees, and percent of large (≥37.9 cm dbh) trees were greater at nest sites than random sites at Camp Ripley. These variables (except average dbh of all trees, which was eliminated from modeling during cluster analysis) also were significant in at least one logistic regression model, with basal area and average overstory dbh being significant in 5 of the 10 models. Morris and Lemon (1983) and Titus and Mosher (1981) also reported larger basal area at nest sites than at random sites, and Woodrey (1986) reported a greater number of trees larger than 50 cm dbh at nest sites than at random sites. The significance of these variables at Camp Ripley but not in the Chippewa may be the result of overall larger basal area in the Chippewa. Basal area was larger at random sites in the Chippewa than at nest sites at Camp Ripley (*t*-test: $t = 2.17$, 56 df, $P = 0.03$). Similarly, average dbh of all trees and percent of large (≥37.9 cm dbh) trees were larger at Chippewa random sites than at Camp Ripley random sites ($t = 2.79$, 56 df, $P = 0.007$; $t = 2.93$, 56 df, $P = 0.005$; respectively), while values at nest sites were comparable between the two study areas (Table 1). These results indicate that sites with large trees were more abundant in the Chippewa than at Camp Ripley.

When all data were combined for logistic regression modeling, nest tree dbh, distance to permanent water, basal area, and canopy height were consistently significant predictors of nest sites versus random sites. The model using cross terms was created to investigate the possibility that a variable might be significant at one area but not the other. Basal area and distance to permanent water were significant at Camp Ripley but not in the Chippewa. These results are consistent with the univariate analyses that indicate both large trees and water were more abundant in the Chippewa than at Camp Ripley. These variables appeared in the models of all nests because sample size at Camp Ripley was twice that of the Chippewa. Thus, nest tree dbh and canopy height were the only two variables that were consistent predictors of nest sites versus random sites across study areas, indicating selection of sites with large trees. These results suggest that young forests are less suitable as nest sites for Red-shouldered Hawks than mature stands with large trees. Cutting rotations of less than 50 years would not allow trees to reach the minimum age of the nest trees used in this study.

Several variables that did not differ between nest and random sites in paired *t*-tests and were not useful by themselves in separating nest sites from random points in logistic regression models were significant predictors of nest versus random sites in logistic regression models when paired with other variables. For example, percent of medium–small trees by itself was not useful in separating nest sites from random sites in the Chippewa, but the model with percent of medium–small trees and nest tree dbh was a better predictor of nest sites versus random sites than either variable alone. Although there may be an interaction between the variables that makes their combination a better predictor, it seems more likely that spurious relationships between variables with small samples sizes result in apparent significance when there is none. Only 3 of the 20 nest trees in the Chippewa were smaller than their paired random trees; if the site with the largest negative difference between size of the nest tree and the paired site center tree is eliminated from the analysis, percent of medium–small trees is no longer a significant predictor of random versus nest sites. That the removal of one nest from the data set changes the models so dramatically suggests that percent of medium–small trees, and probably other variables that were not significant in paired *t*-tests, do not have any biological significance in discriminating nest sites from random sites. The frequent occurrence of perfect fit models when data from the two study areas were analyzed separately also was probably attributable to small sample sizes.

Red-shouldered Hawks appeared to select sites close to water and with large trees when choosing nest locations, but there was no evidence that these habitat characteristics affected nesting success at Camp Ripley. The two habitat features that differed between successful and unsuccessful nests indicate more small trees and a closer distance to harvested areas at successful nests. These features may relate to habitat quality (perhaps prey availability), or may simply be a statistical artifact. Other researchers (Bednarz and Dinsmore 1981,

Armstrong and Euler 1982) have suggested Red-shouldered Hawks need large forest blocks for successful breeding and avoid openings and human activities. Forest edge is also important to Red-shouldered Hawks as foraging habitat (Craighead and Craighead 1956, Bednarz and Dinsmore 1981), although in these cases openings were provided by wetlands and not harvested upland area.

Despite apparently higher availability of suitable nest sites in the Chippewa than at Camp Ripley, productivity in the Chippewa was lower than at Camp Ripley. Sixty percent of nests at Camp Ripley fledged young, whereas at most 15% of the nests found in the Chippewa fledged young. The fledging rate in the Chippewa was also lower than reported in other studies (Henny et al. 1973, Wiley 1975, Crocoll and Parker 1989). Factors unrelated to nest site availability might be responsible for low nesting success in the Chippewa. Light weights of chicks and chicks dying in the nest (M. A. McLeod, unpubl. data) were consistent with low food availability. With only two years of data it is impossible to determine whether low reproductive rates in the Chippewa were the result of annual variation or are chronic. If nesting success at the northern edge of the breeding range is consistently low regardless of forest structure, these populations may be maintained through immigration from other, more productive areas.

ACKNOWLEDGMENTS

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